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The Cognitive Development of Visual Literacy for Scientific Symbolic Problem Solving

Michael R. Taber, Elizabeth Benedict, Elizabeth Waterman
Colorado College (USA)
mike.taber@coloradocollege.edu, elizabeth.benedict@coloradocollege.edu, elizabeth.waterman@coloradocollege.edu

Abstract

In many scientific interpretational situations, the available information inputs (i.e., plurality of data) are often expressed to the user in symbolic representations. To what extent does the novice scientist, a student just learning science, have the capacity to holistically interpret the data? Where is the science learner in the development of visual literacy in terms of spatial thinking, re-representations of information in visual format(s), and communication of complex patterns? Learners with more developed linguistic skills, both verbal and phonological, should be better equipped to understand and solve visual problems. This preliminary study examines how well participants employ visual literacy skills in solving a symbolically driven problem. Ninety-two participants in the study were undergraduates at two different institutions: Colorado College and the University of Oregon. Participants were asked to determine the elements on an unseen sixth face on a cube by recording observations and engaging in conversation. Results showed that participants who did indeed possess higher linguistic fortitude and spatial observation and reasoning skills were more likely to correctly identify all seven elements on the unknown cube face.

1. Introduction

The development of deductive spatial reasoning is closely related to the development of both literacy and visual observation skills [1], [2]. Observations are processed by the brain and related to beliefs, expectations, previous experiences and significant prior knowledge [3]. As the observations are interpreted, the brain develops questions and creates hypotheses. Learners react to a formulated question by encoding observations into mental representations (cognitive mapping). These mental representations become the immediate knowledge for developing or refining questions and hypotheses.

The ability to simultaneously process multiple inputs leads to more successful reasoning skills, both inductive and deductive [4]. Learners encode observations and into mental representations (cognitive mapping). These mental representations become the prior knowledge for processing future observations, ultimately developing or refining questions and hypotheses essential for solving abstract problems [5]. Visual representations created by learners further develop mental cognition in parallel with linguistic ability development, particularly in socio-constructivist learning environments [1], [2]. Learners with high verbal skills have an easier time solving abstract problems than those with low verbal skills.

Developing diagram literacy cognitively allows learners to understand, conceptualize, and solve abstract problems [6]. The more diagram a literate learner is, the better equipped he/she will be to solve abstract problems independently and think critically.

Learners with less developed diagram literacy tend to rely on others to assist in solving an abstract problem [5].

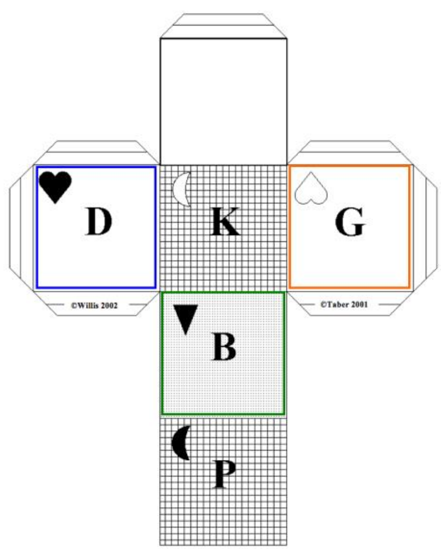
Strategic, cognitive flexibility is the notion that a learner utilizes more than one strategy to solve a problem based on their tactile and linguistic skill development [7]. The strategies influence a learner's decision to draw a schematic or use words as representations of observations [8]. Therefore, we would expect learners with more developed strategic, cognitive flexibility to utilize both schematic and written observations in solving an abstract problem. While learners create both schematic and non-schematic drawings, schematic drawings are positively correlated to successful abstract problem solving, while non-schematic drawings are negatively correlated [1]. The more detailed a schematic drawing is the more likely the learner will solve the problem correctly. If learners are taught to effectively use visual representations with enriched diagram literacy skill development, many more students will achieve greater academic performance in solving abstract problems.

2. Methods

This preliminary study consisted of seventy-six undergraduate students from Colorado College and sixteen undergraduate students at the University of Oregon. Participants were chosen both by random and as an exercise in an introductory science courses and an introductory education course.

A six-sided cube was set in front of participants in groups of two to four (Figure 1). Participants were not permitted to touch or move the cube. Each cube faces had seven elements: background pattern; geometric shape; shape shading; shape location; shape orientation; letter; and, border color. All participants were given a sheet of paper with the question, "What is on the bottom of the cube?" Participants were encouraged to record their observations and findings (Figure 2).

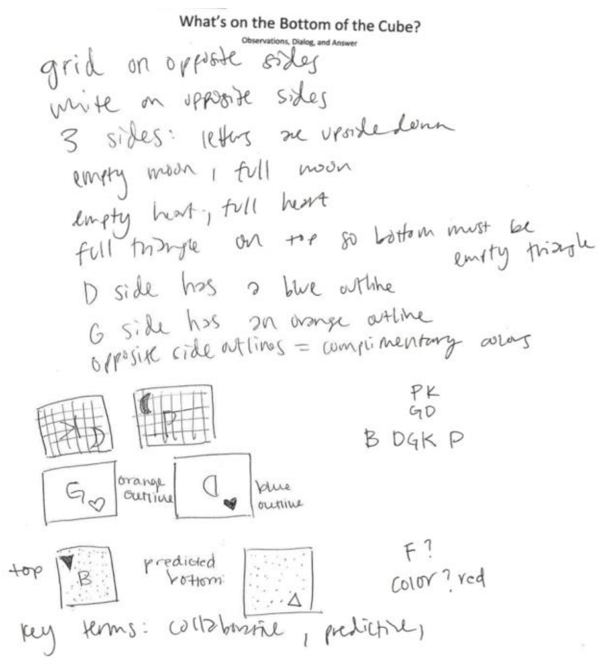
Figure 1. *The "cube" puzzle given to participants. The side with the letter "B" was facing up.*



A grounded theory approach [9] was used to primarily determine generality across participants with regards to written observational details and deductive reasoning, common expectations in scientific courses. The grounded theory approach allowed for qualitative data to tell a story. The story was then used for examining the process (observations) by which participants engaged in visual literacy.

Papers were collected from all participants. An open and axial coding process revealed four discrete categories: use of the English alphabet; statements of logic; a drawing representing the sixth, unknown face; and observational notes. The four categories were then coded with scaled, numerical representations. For example, there was a possibility of a participant to note seven elements on the five visible faces for a total of 35 possible notations. One point was award to each recorded observation. In the case of participant in Figure 2, all but the blue outline on face "B" was noted, scoring 34 out of 35 possible points. All data was organized and analyzed using SPSS® statistical software.

Figure 2. *A sample sheet collected from a participant in the study. The participant provided significant detail on each element, even providing correct perspective in the drawings. The participant also provided some detail on his/her logic with regards to other possible elements on the unknown face.*



In addition to collecting participant papers for data analysis, we observed groups during the exercise (except at the University of Oregon). We collected information on questions asked and the degree to which participants struggled with determining the contents of the unknown face. At the end of the exercise (in courses) groups shared their results with the rest of participants in class.

3. Results and Discussion

A majority (88%) of the participants concluded that the background was "dots," similar to the background on the top face ("B" in Figure 1). The basic reasoning provided by most was "opposite sides were the same." The premise to conclusion logic makes sense as the opposite faces ("G" and "D" are blank and "K" and "P" are grids).

A significant number of participants concluded the geometric shape on the unknown face was a triangle (95.7%) that was empty (84.8%). Most groups reached "dots" and "empty triangle" conclusion rather quickly.

However, difficulty arose when participants realized or were prompted by the question, "What is the orientation of the triangle"? A majority of the participants (48.9%) did conclude that the triangle was facing "up" relative to the position of the yet-to-be-determined letter. Difficulty in determining the orientation appeared to be originating from two possibilities: 1) participants who could not visualize the crescent moon as a mirror image or 2) participants could not visualize the orientation of the triangle relative to the logical orientation of the letter. Further research on the correlation between spatial recognition of the triangle orientation might provide additional insight.

Spatial reasoning also became evident when students were prompted to determine the location of the triangle on the face. A majority (34.8%) accurately concluded "upper left" in relation to the correct placement of the letter on the unknown face. However, a significant number of participants (29.3%) could not determine the answer. Observations conclude that students could not spatially translate the visible faces in order to determine the location of the triangle. Further interviewing of participants should provide more insight.

Participants began working on the letter element at different times during the exercise. Some noted the initial difficulty and quickly solved the background and shape elements before undertaking the task of determining the letter. In general, the determination of the letter was lead by one person in the group; primarily by the person who began writing down the English alphabet and noting which letters were visible.

The most popular conclusion for the letter was "V" (37%) followed by "A" (21.7%) and "F" (10.9%). Participants who concluded "V" used the logic of counting the space between the letters (Figure 3). Participants used an American cultural practice of counting, beginning with the number "1." Students who selected the letter "A" used similar logic, concluding that there is an equal chance that there would be zero letters between two (A and B).

Figure 3. *A Schematic representation of the logic of determining the letter "V" using the English alphabet. One letter separates "B" and "D," two letters separate "D" and "G," etc. The letter "V" is determined based on five letters separating "P" from "V."*

A	<u>B</u>	C	<u>D</u>	E	F	<u>G</u>	H	I	J	<u>K</u>	L	M	N	O	<u>P</u>	Q	R	S	T	U	**<u>V</u>**	W	X	Y	Z
		1		2				3					4					**5**							

The final element to solve was whether the unknown face had a color border. A majority of participants could not determine an answer (38%). For those who concluded there was a border, determined the color was "red" (35.9%). The logical conclusion was reaching knowing complimentary colors for the visible pair: orange-blue or green-*red*.

We observed that participants who provided detailed notes were more likely to provide a schematic drawing of their answer (p=0.663) *and* provide statements (p=0.331) of reasoning (Table 1).

Table 1. *Pearson 2-tailed correlations for four variables related to written representation of the answer, reasoning, and detailed observations (**Correlation is significant at the 0.01 level; *Correlation is significant at the 0.05 level).*

		Written	Picture of the	Reasoning	Detailed
Detailed Observations	Pearson	.055	.263*	.331**	
	Sig. (2-tailed)	.601	.011	.001	
	N	92	92	92	

4. Conclusion

Participants who provided more detailed notes, especially noting all the elements on each face and utilized the strategy of writing down the English alphabet were more likely to correctly identify the seven elements on the unknown face than participants with limited notation. In addition, we found that groups of three to four were more likely to have all participants successfully identify the seven elements than groups of two. This is more likely due to the greater chance of having at least one person in a larger group have more developed linguistic and cognitive, strategic skills.

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